# CHAPTER 6

# COMMUNICATIONS AND LIGHTING

Many advances in lighting and communications have occurred in the past few years. With the cost of energy rising daily and the demand for accurate and reliable communications, any system that provides a higher level of efficiency must be considered.

In this chapter we will discuss public address systems, interoffice communications, and the fundamentals of fiber-optic communication cables and components. This chapter also will cover area streetlighting, floodlighting, and security lighting.

## PUBLIC ADDRESS SYSTEM

The type of public address system that you will install, maintain, and troubleshoot is intended for installation in administrative and living quarter areas. This system will be used for general announcements, for indoor talk-back paging, and to entertain or address personnel.

A common system authorized by the General Services Administration consists of one 100-watt solid-state amplifier, four trumpet speakers with drivers, two paging speakers, one dynamic microphone with floor stand, and all accessory terminal fittings and hardware required to operate this system. The set will conform to the design and functional test requirements of Underwriters Laboratory (UL) 813 Standard and the wiring and design requirements of the National Fiie Protection Association (NFPA) 70.

## INSTALLATION

Before you install a public address system, refer to the National Electrical Code© (NEC©) and the manufacturers' recommendations. Several factors must be met for the permanent or temporary installation of a public address (PA.) system.

We will discuss these factors for the installation of a public address system, consisting of an amplifier (console), speakers, and cable that are approved for this system.

### Amplifier

The solid-state amplifier comes with an ac power cord that is terminated in a three-prong plug. The power cord must be plugged into a three-wire, 120-volt, 60-hertz grounded outlet. The cord will ground the amplifier and the auxiliary power receptacle. The auxiliary power receptacle is a three-wire grounded outlet that supplies power to accessory sound equipment. The receptacle will supply power only as long as the amplifier is connected to a 120-volt power source and turned on.

The amplifier will be internally wired with a circuit breaker for protection. If the breaker trips, turn off the amplifier and reset the circuit breaker. Turn on the amplifier, and, if the breaker trips again, do not attempt to reset it. A problem exists that you will need to investigate and correct.

### Speakers

The speakers will be weatherproof and have adjustable mounting brackets. The input impedance of the speakers will match the amplifier output with a low-frequency cutoff, as shown in figure 6-1.

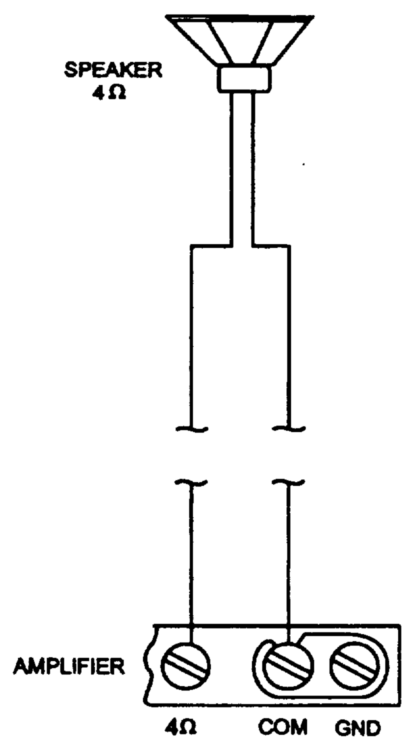


**Figure 6-1.—Total speaker impedance matches the output impedance of the amplifier.**

The output speaker voltage will be either 25 or 70.7 volts. The speaker will have a microphone precedence over other input singles and four output terminals with circuit protection.

Speaker installation is an important element whenever you install a P.A. system. No matter how good the amplifier is, if the speaker installation is not done properly, the sound produced will be inadequate. There are a number of factors you must consider when you install speakers. The placement and connection of speakers is the most important step. For indoor systems, two types of placement can be used. The speakers may be placed flat against a wall and the speaker turned so that it will radiate sound at an angle from the wall. The other type of placement is to mount the speakers in the corners of a room; for example, alcoves, balconies, booths, and dividing walls. A variation of these two methods mentioned may be considered for installation.

For outdoor systems, the main considerations are the area to be covered and the direction of sound. Highly directive trumpet speakers are normally used for an outdoor area.

When connecting speakers together, you must consider impedance matching and phase relations. Mismatching the impedance of a speaker to an amplifier output in either an upward or a downward manner will produce different effects. Mismatching upward (connecting an 8-ohm speaker to the 4-ohm output) will affect the power delivered to the speaker. Power loss will be about proportional to the upward impedance mismatch; in this case, about 50 percent. As a general rule, no serious frequency response deficiency will be noted and cannot damage a well-designed amplifier. Mismatching downward (connecting a 4-ohm speaker to an 8-ohm output) should always be avoided. It will reduce the amplifier power output and cause an overload on the output side with possible damage to the amplifier.

Figure 6-2 shows an example of two speakers connected in series. Add the individual speaker impedances together to obtain the total matching impedance. The formula for this where Z = impedance is $Zt = Z1 + Z2$.

For parallel connection (fig. 6-3) add the reciprocal of the individual speaker impedances together to obtain the reciprocal of the total matching impedance. The formula for parallel connections is as follows:

For series/parallel connections, combine the two formulas as the speaker connections indicate; for example, see figure 6-4, and apply the series formula for A and B, then for C and D. Take the results of this and apply the parallel formula to obtain the final matching impedance.

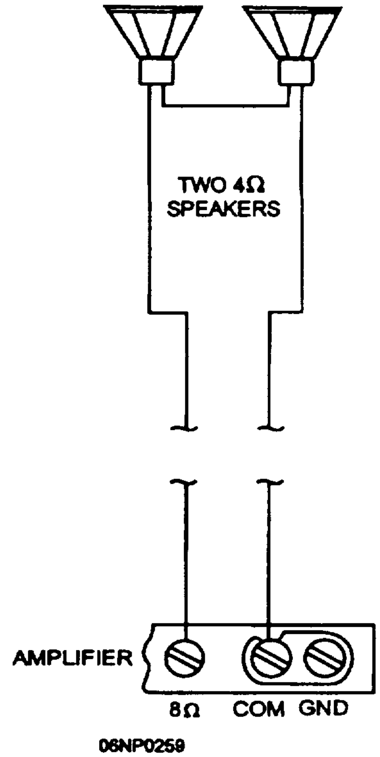


**Figure 6-2.—Two speakers connected in series.**

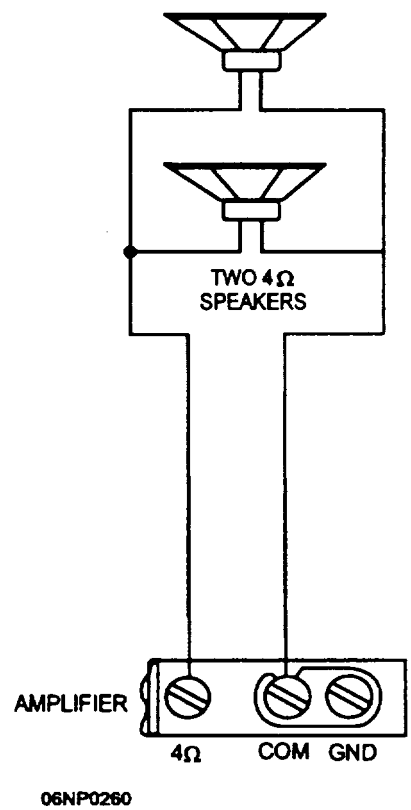


**Figure 6-3.—Matching two speakers connected in parallel.**

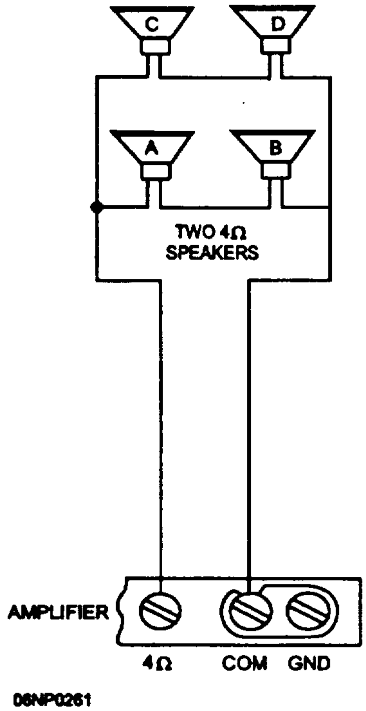

**Figure 6-4.—Matching four speakers connected in series parallel.**

When you use more than one speaker in a sound system installation, phase the speakers to reduce the cancellation effect, as shown in figure 6-5. Speakers out of phase will lose up to one half of their normal volume and operate with degraded tone quality.

For speakers facing in the same general direction, they are in phase when their respective diaphragms move in the same direction. This is achieved by connecting the speakers + to + and - to -. For speakers facing each other, they are in phase when their respective diaphragms move in opposite Directions. This is achieved by connecting the speakers + to - and - to +.

Efficient transfer of power from the amplifier to the speakers is the prime consideration in sound system connections. Basically, there are two methods of connection. One connection runs from the amplifier directly to the speaker voice coils and the other connection runs from the amplifier to the speaker voice coils through a transformer. You should use the first method with short runs (not over 200 feet) of wire and a simple speaker arrangement with low impedances. Use the second method whenever a 15-percent power loss in the transmission lines is noted or when wire runs are more than 200 feet, or there is a complex speaker arrangement. Constant voltage transformers are most commonly used for this purpose although impedance-matching transformers may be used. For an in-depth look, refer to NEETS, Module 8, *Introduction to Amplifiers.*

## Cable

Cable installations are just as important as the other component installations. The cable used should be recommended by the manufacturer and in compliance with the NEC©. For the best results in sound, a two-conductor shielded cable should be used.

In complex systems where the input lines are run in close proximity to the speaker lines for long distances, currents in the speaker lines may be picked up by the input lines. When these stray currents are fed back to the amplifier, cross talk and hum can be heard, or the amplifier may oscillate. Because of this, balanced line connections are recommended when long input and speaker lines are run close together. A balanced line is achieved by ungrounding the common terminal, leaving the outputs floating. Any current that develops on one side of the line and is offset by an equal and opposite current on the other side is called a BALANCED LINE. This reduces the possibility of creating stray currents in nearby input tines.

If hum is encountered with a balanced line, it may be necessary to run a shielded two-conductor cable to the speakers and ground the cable at the amplifier.

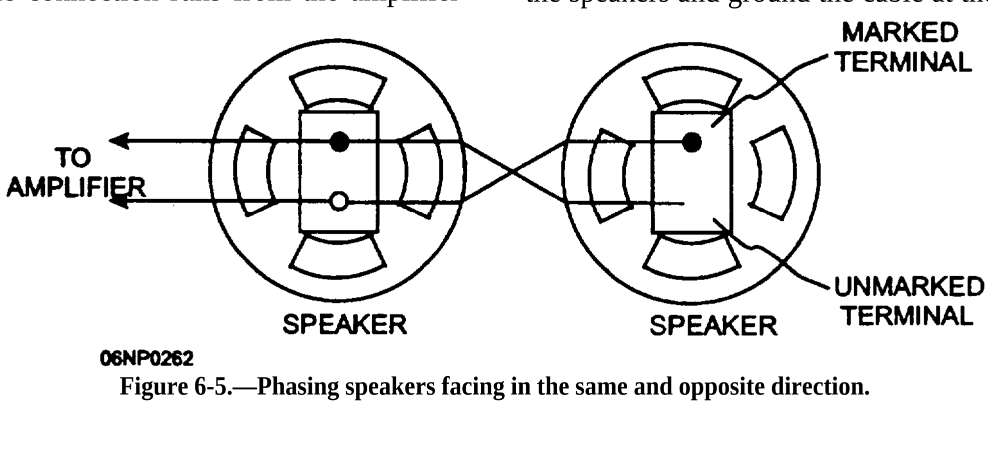

**Figure 6-5.—Phasing speakers facing in the same and opposite direction.**

## MAINTENANCE AND REPAIR

The best designed and built equipment occasionally develops faults. There are many factors that cause faults: moving equipment, atmospheric conditions, and the age of the equipment, just to name a few. A preventive maintenance schedule should be developed that requires a set routine of periodic tests, checks, and inspections to head off trouble before it develops.

When repairing a PA. system, you should always follow the manufacturers' recommendations and guidelines. Replacing faulty parts with the exact replacement parts is always the correct procedure.

Trouble in a public address system is often caused by nothing more than a loose connection or a break in the cable shield. Check for simple faults of this type before you begin a lengthy test of the system.

The identification and location of serious troubles in a system may require the use of signal-tracing equipment, such as an audio-signal generator, a meter, or an oscilloscope. When you test the electrical circuit, the most important point to remember is that you need to pinpoint the location of the trouble. A careful study of the circuit diagram is essential.

Some of the problems that cause defects in a P.A. system are poor solder connections and loose mechanical connections. When checking solder connections, make certain that both metals are absolutely clean and that the completed soldering job is firm and durable. Faulty soldering in a P.A. system can cause defects that are difficult to identify and locate. Too much solder can cause shorts in microphone connections that may not be visible.

Mechanical connections are easy to check; just ensure that all connections with a mechanical connector are tight. This type of connector will be found in the rear of the amplifier or in the console and speakers.

## INTEROFFICE COMMUNICATION SYSTEMS

An interoffice communication system is used to transmit orders and information among offices that are only a short distance apart. Frequently, such offices are in the same building. When an interoffice communication system is used, you are responsible for the installation and maintenance of the system.

## CONFIGURATIONS

An intercom system consists of two basic configurations: the all-master system and the single-master multiple remote system.

With the all-master system, any station can call any other station or several stations can be connected together for a conference.

With the single-master multiple remote system, the single-master station can selectively call any remote station, and any remote can call the master station.

## COMPONENTS

Basically, an intercom system consists of one or more stations, a junction box, one or more remote speaker units, and the wire necessary to make the connections.

The basic parts of a master station consist of a speaker-microphone, a selector switch panel, a combination volume control, ON/OFF switch, a pilot light, and a listen-talk switch, all of which are mounted in a cabinet.

The basic parts of a remote speaker unit consist of a speaker-microphone, a push switch for signaling the master, and a terminal board for interconnection to the master station.

## MASTER AND REMOTE STATION INSTALLATION

You can accomplish the installation of an intercom system easily if you follow the manufacturers' instructions and the NEC© guidelines.

Any combination of master stations and remote stations up to the capacity of the master station can be used. Where it is not necessary for remote stations to communicate among themselves, you should usually install only one master station.

Install the master station within reach of a 120-volt, 60-hertz ac power outlet. The master station and the remote stations should be installed on the desk or in the working spaces of the personnel who will use them. If some of the units are to be installed outdoors, take the necessary precautions to protect them from adverse weather conditions.

The size of cable to be used in making connections between units is governed by the length of wire and the type of system you install. The maximum wire resistance permissible will be stated in the operating instructions of the manufacturer's literature. Component and cable installation will depend on the type of system to be installed.

After the cable is installed, check the resistance with an ohmmeter. Make certain that the maximum permissible resistance is not exceeded and that there are no opens, grounds, or shorts.

**NOTE:** Always follow the installation instructions that come with each system.

## MAINTENANCE OF INTEROFFICE COMMUNICATIONS SYSTEMS

In general there are four basic steps in intercom maintenance: inspect, tighten, clean, and adjust. Inspection is always of primary importance.

The components in an intercom system are readily accessible, and, for the most part, can be replaced when faulty.

With the solid-state devices of today, all maintenance programs are basically the same. One of the first and the most important factors you must take is to consult the manufacturers' recommendations and guidelines when performing maintenance on any intercom system.

Common troubles within an intercom system are normally nothing more than loose connections or breaks in the cable. If a component should need replacement, be sure to replace it with the manufacturer's suggested component.

# FIBER OPTICS

People have used light to transmit information for hundreds of years. However, it was not until the 1960s with the invention of the laser that widespread interest in optical (light) systems for data communications began. The invention of the laser prompted researchers to study the potential of fiber optics for data communications, sensing, and other applications. Laser systems could send a much larger amount of data than the telephone, microwave, and other electrical systems. The first experiment with the laser involved letting the laser beam transmit freely through the air. Also, researchers conducted experiments that transmitted the laser beam through different types of waveguides. Glass fibers, gas-filled pipes, and tubes with focusing lenses are examples of optical waveguides.

Glass fibers soon became the preferred medium for fiber-optic research. Initially, the large losses in the optical fibers prevented coaxial cables from being replaced. **Loss** is the decrease in the amount of light reaching the end of the fiber. Early fibers had losses around 1,000 dB/km, making them impractical for communications use. In 1969, several scientists concluded that impurities in the fiber material caused the signal loss in optical fibers. The basic fiber material did not prevent the light signal from reaching the end of the fiber. These researchers believed it was possible to reduce the losses in optical fibers by removing the impurities. By removing the impurities, researchers made possible the construction of low-loss optical fibers.

Developments in semiconductor technology that provided the necessary light sources and detectors furthered the development of fiber optics. Conventional light sources, such as lamps or lasers, were not easily used in fiber-optic systems. These light sources tended to be too large and required lens systems to launch light into the fiber. In 1971, Bell Laboratories developed a small area light-emitting diode (LED). This light source was suitable for a low-loss coupling to optical fibers. Researchers could then perform source-to-fiber jointing easily and repeatedly. Early semiconductor sources had operating lifetimes of only a few hours; however, by 1973, projected lifetimes of lasers advanced from a few hours to greater than 1,000 hours. By 1977, projected lifetimes of lasers advanced to greater than 7,000 hours. By 1979, these devices were available with projected lifetimes of more than 100,000 hours.

In addition, researchers also continued to develop new fiber-optic parts. The types of new parts developed included low-loss fibers and fiber cables, splices, and connectors. These parts permitted demonstration and research on complete fiber-optic systems.

Advances in fiber optics have permitted the introduction of fiber optics into present applications. These applications are mostly in the telephone long-haul systems but are growing to include cable television, computer networks, video systems, and data links. Research should increase system performance and provide solutions to existing problems in conventional applications. The impressive results from early research show there are many advantages offered by fiber-optic systems.

## FIBER-OPTIC SYSTEMS

System design has centered on long-haul communications and the subscriber-loop plants. The subscriber-loop plant is the part of a system that connects a subscriber to the nearest switching center. Cable television is an example. Also, limited work has been done on short-distance applications and some military systems. Initially, central office trunking required multimode optical fibers with moderate to good performance. Fiber performance depends on the amount of loss and signal distortion introduced by the fiber when it is operating at a specific wavelength. Two basic types of optical fibers are used in industry: multimode fibers and single mode fibers.

Future system design improvements depend on continued research. Researchers expect fiber-optic product improvements to upgrade performance and lower costs for short-distance applications. Future systems center on broadband services that will allow transmission of voice, video, and data. Services will include television, data retrieval, video word processing, electronic mail, banking, and shopping.

## ADVANTAGES AND DISADVANTAGES OF FIBER OPTICS

Fiber-optic systems have many attractive features that are superior to electrical systems. These include improved system performance, immunity to electrical noise, signal security, and improved safety and electrical isolation. Other advantages include reduced size and weight, environmental protection, and overall system economy. Table 6-1 details the main advantages of fiber-optic systems.

Despite the many advantages of fiber-optic systems, there are some disadvantages. Because of the relative newness of the technology, fiber-optic components are expensive. Fiber-optic transmitters and receivers are still relatively expensive compared to electrical interfaces. The lack of standardization in the industry has also limited the acceptance of fiber optics. Many industries are more comfortable with the use of electrical systems and are reluctant to switch to fiber optics; however, industry researchers are eliminating these disadvantages.

Standards committees are addressing fiber-optic part and test standardization. The cost to install fiber-optic systems is falling because of an increase in the use of fiber-optic technology. Published articles, conferences, and lectures on fiber optics have begun to educate managers and technicians. As the technology matures, the use of fiber optics will increase because of its many advantages over electrical systems.

**Table 6-1.—Advantages of Fiber Optics**

| | |
|---|---|
| System Performance | • Greatly increased band. width and capacity<br>• Lower signal attenuatior (loss) |
| Immunity to Electrical Noise | • Immune to noise (electromagnetic interference [EMI] and radio-frequency interference [RFI])<br>• No cross talk<br>• Low bit error rates |
| Signal Security | • Difficult to tap<br>• Nonconductive (does no radiate signals) |
| Electrical Isolation | • No common ground required<br>• Freedom from short circuit and sparks |
| Size and Weight | • Reduced size and weigh cables |
| Environmental Protection | • Resistant to radiation and corrosion<br>• Resistant to temperature variations<br>• Improved ruggedness and flexibility<br>• Less restrictive in harsh environments |
| Overall System Economy | • Low per-channel cost<br>• Lower installation cost<br>• Silica is the principal abundant, and inexpensive material (source is sand) |

## BASIC STRUCTURE OF AN OPTICAL FIBER

The basic structure of an optical fiber consists of three parts: the **core,** the **cladding,** and the **coating** or **buffer.** The basic structure of an optical fiber is shown in figure 6-6. The **core** is a cylindrical rod of dielectric material. Dielectric material conducts no electricity. Light propagates mainly along the core of the fiber. The core is generally made of glass. The core is surrounded by a layer of material called the **cladding.** Even though light will propagate along the fiber core without the layer of cladding material, the cladding does perform some necessary functions.

The **cladding** layer is made of a dielectric material. Cladding is generally made of glass or plastic and performs the following functions:

- Reduces loss of light from the core into the surrounding air
- Reduces scattering loss at the surface of the core
- Protects the fiber from absorbing surface contaminants
- Adds mechanical strength

For extra protection, the cladding is enclosed in an additional layer called the **coating** or **buffer.**

The **coating** or **buffer** is a layer of material used to protect an optical fiber from physical damage. The material used for a buffer is a type of plastic. The buffer is elastic in nature and prevents abrasions. Also, the buffer prevents the optical fiber from scattering losses caused by microbends. Microbends occur when an optical fiber is placed on a rough and distorted surface. Microbends are discussed later in this chapter.

## OPTICAL CABLES

Optical fibers have small cross-sectional areas. Without protection, optical fibers are fragile and can be broken. The optical cable structure protects optical fibers from environmental damage. Cable structure includes buffers, strength members, and jackets. Many factors influence the design of fiber-optic cables. The cable design relates to the intended application of the cable. Properly designed optical cables perform the following functions:

- Protect optical fibers from damage and breakage during installation and over the lifetime of the fiber.
- Provide stable fiber transmission characteristics compared with uncabled fibers. Stable transmission includes stable operationin extreme climate conditions.
- Maintain the physical integrity of the optical fiber by reducing the mechanical stresses placed on the fiber during installation and use. Static fatigue caused by tension, torsion, compression, and bending can reduce the lifetime of an optical fiber.

## FIBER BUFFERS

Coatings and buffers protect the optical fiber from breakage and loss caused by microbends. During the fiber drawing process, the addition of a primary coating protects the bare glass from abrasions and other surface contaminants. For additional protection, manufacturers add a layer of buffer material. The buffer material provides additional mechanical protection for the fiber and helps preserve the inherent strength of the fiber.

Manufacturers use a variety of techniques to buffer optical fibers. The types of fiber buffers include tight-buffered, loose-tube, and gel-filled loose-

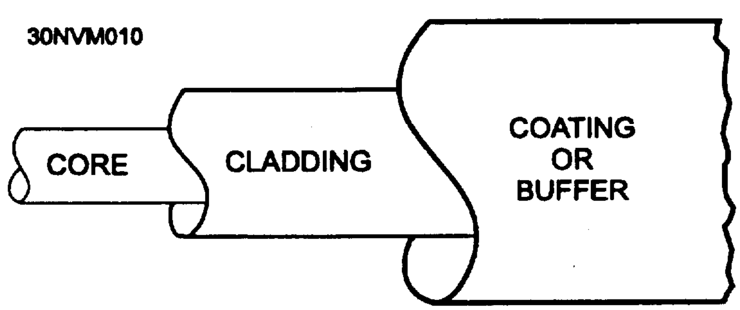


**Figure 6-6.—Basic structure of an optical fiber.**

tube. Figure 6-7 shows each type of fiber buffer. The choice of buffering techniques depends on the intended application. In large fiber count commercial applications, manufacturers use the loose-tube buffers. In commercial building and Navy applications, manufacturers use tight buffers.

## CABLE STRENGTH AND SUPPORT MEMBERS

Fiber-optic cables use strength members to increase the strength of the cable and protect the fiber from strain. Fiber-optic cables may use central support members in cable construction The central support members generally have buffered fibers or single fiber subcables stranded over their surface in a structured, helical manner. The central members may support the optical fibers as cable strength members or may only serve as fillers. Strength and support members must be light and flexible. The materials used for strength and support include steel wire and textile fibers (such as nylon and arimid yarn). They also include carbon fibers, glass fibers, and glass reinforced plastics.

## CABLE JACKET MATERIAL

The jacket, or sheath, material provides extra environmental and mechanical protection. Jacket materials may possess any number of the following properties:

- Low smoke generation
- Low toxicity
- Low halogen content
- Flame retardance
- Fluid resistance
- High abrasion resistance
- Stable performance over temperature

It is difficult to produce a material compound that satisfies every requirement without being too costly. Jacket materials currently used include polyethylene, polyvinyl chloride, polyurethane, and polyester elastomers. Most commercial jacket materials are unsuitable for use in naval applications.

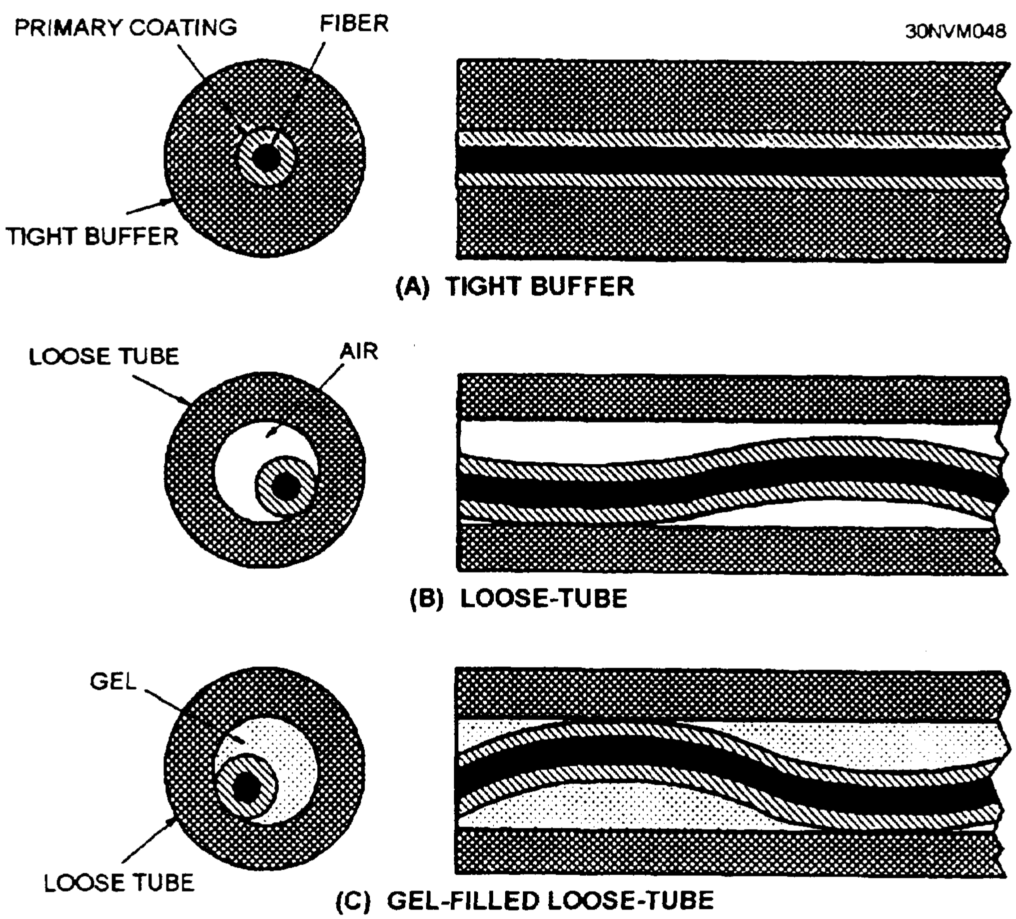


**Figure 6-7.—Tight-buffered, loose-tube, and gel-filled loose-tube buffer techniques.**

## CABLE DESIGNS

Manufacturers design fiber-optic cables for specific applications. For example, is the cable buried underground or hung from telephone poles? Is the cable snaked through cableways, submerged in water, or just laid on the ground? Is the cable used in industrial, telecommunication, utility, or military applications? Each type of application may require a slightly different cable design.

Agreement on standard cable designs is difficult. Cable design choices include jacket materials, water-optic cables. Some fiber-optic cables are used in commercial applications, and others are used in military applications. Standard commercial cable designs will develop over time as fiber-optic technology becomes more established.

## FIBER-OPTIC DATA LINKS

A fiber-optic data link sends input data through fiber-optic components and provides this data as output information. It has the following three basic functions:

- To convert an electrical input signal to an optical signal
- To send the optical signal over an optical fiber
- To convert the optical signal back to an electrical signal

A fiber-optic data link consists of three parts: **transmitter, optical fiber,** and **receiver.** Figure 6-8 is an illustration of a fiber-optic data-link connection. The transmitter, optical fiber, and receiver perform the basic functions of the fiber-optic data link. Each part of the data link is responsible for the successful transfer of the data signal. A fiber-optic data link needs a transmitter that can effectively convert an electrical input signal to an optical signal and launch the data-containing light down the optical fiber. Also, fiber-optic data link needs a receiver that can effectively transform this optical signal back into its original form. This means that the electrical signal provided as data output should exactly match the electrical signal provided as data input.

## FIBER-OPTIC SPLICES

A fiber-optic splice is a permanent fiber joint whose purpose is to establish an optical connection between two individual optical fibers. System design may require that fiber connections have specific optical properties (low loss) that are met only by fiber splicing. Also, fiber-optic splices permit the repair of optical fibers damaged during installation, accident, or stress. System designers generally require fiber splicing whenever repeated connection or disconnection is unnecessary or unwanted.

Mechanical and fusion splicing are two broad categories that describe the techniques used for fiber splicing. A **mechanical** splice is a fiber splice where mechanical fixtures and materials perform fiber alignment and connection. A **fusion splice** is a fiber splice where localized heat fuses or melts the ends of two optical fibers together. Each splicing technique seeks to optimize splice performance and reduce splice loss. Low-loss fiber splicing results from proper fiber end preparation and alignment.

## FIBER-OPTIC CONNECTORS

A fiber-optic connector is a device that permits the coupling of optical power between two optical fibers or two groups of fibers. Designing a device that allows for repeated fiber coupling without significant loss of light is difficult. Fiber-optic connectors must maintain fiber alignment and provide repeatable loss measurements during numerous connections. Fiber-optic connectors should be easy to assemble (in a laboratory or field environment) and should be cost effective. Also, they should be reliable. Fiber-optic connections using connectors should be insensitive to environmental conditions, such as temperature, dust, and moisture. Fiber-optic connector designs attempt to optimize connector performance by meeting each of these conditions.

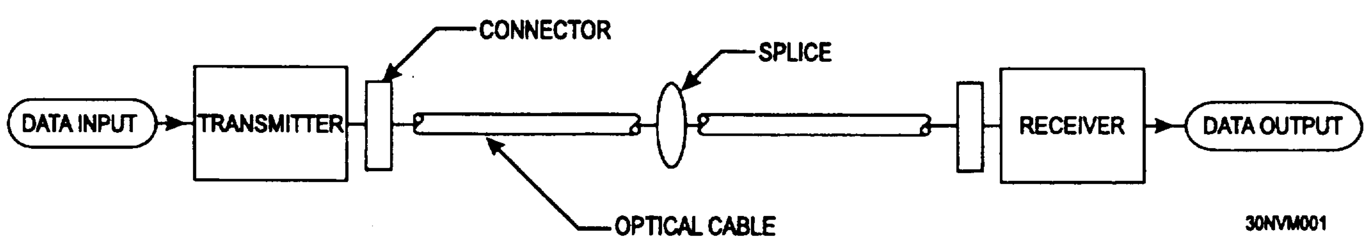


**Figure 6-8.—Parts of a fiber-optic data link.**

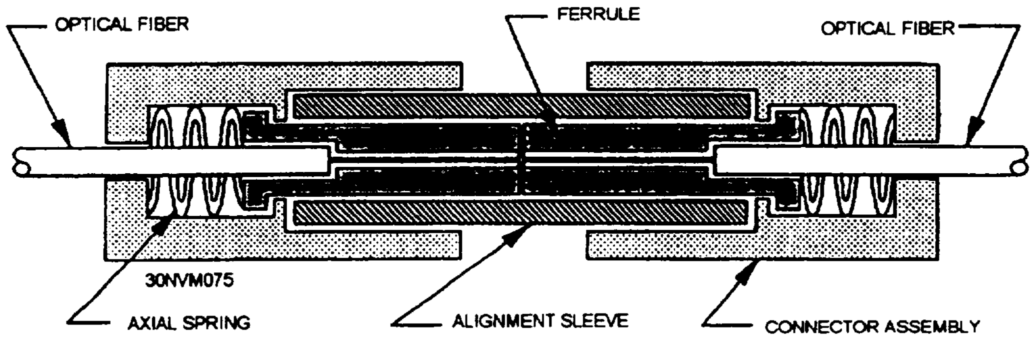


**Figure 6-9.—Basic ferrule connector design.**

**Butt-jointed connectors** and **expanded-beam connectors** are the two basic types of fiber-optic connectors. Fiber-optic **butt-jointed connectors** align and bring the prepared ends of two fibers into close contact. The end faces of some butt-jointed connectors touch, but others do not. depending upon the connector design. Types of butt-jointed connectors include cylindrical ferrule and biconical connectors. Figure 6-9 shows a basic ferrule design. Fiber-optic **expanded-beam connectors** use two lenses to first expand and then refocus the light from the transmitting fiber into the receiving fiber. Single fiber butt-jointed and expanded-beam connectors normally consist of two plugs and an adapter (coupling device) (fig. 6-10).

**Expanded-beam connector** shown in figure 6-11 uses two lenses to expand and then refocus the light from the transmitting fiber into the receiving fiber. Expanded-beam connectors are normally plug-adapter-plug type connections Fiber separation and lateral misalignment are less critical in expanded-beam coupling than in butt-jointing. The same amount of fiber separation and lateral misalignment in expanded-beam coupling produces a lower coupling loss than in butt-jointing; however, angular misalignment is more critical. The same amount of angular misalignment in expanded-beam coupling produces a higher loss than in butt-jointing. Also, expanded-beam connectors are much harder to produce. Resent applications for expanded-beam connectors include multifiber connections, edge connections for printed circuit boards, and other applications.

## FIBER-OPTIC COUPLERS

Some fiber-optic data links require more than simple point-to-point connections. These data links may be of a much more complex design that requires multiport or other types of connections. In many cases, these types of systems require fiber-optic components that can redistribute (combine or split) optical signals throughout the system.

One type of fiber-optic component that allows for the redistribution of optical signals is a fiber-optic coupler. A fiber-optic coupler is a device that can distribute the optical signal (power) from one fiber among two or more fibers. Also, a fiber-optic coupler

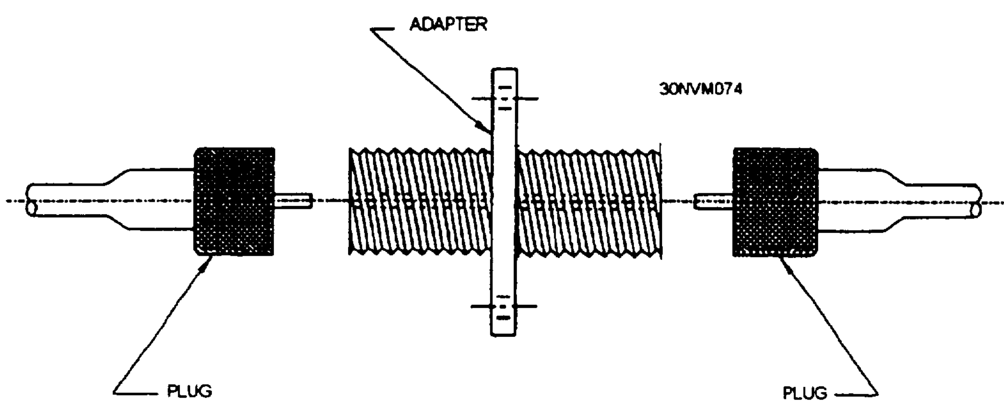


**Figure 6-10.—Plug-adapter-plug configuration.**

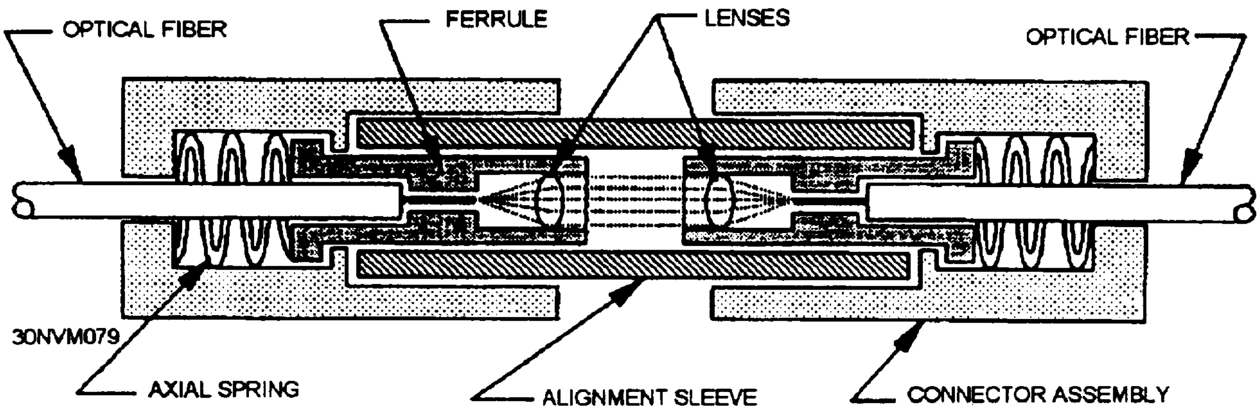


**Figure 6-11.—Expanded-beam connector operation.**

can combine the optical signal from two or more fibers into a single fiber.

Fiber-optic couplers can be either active or passive devices. The difference between active and passive couplers is that a **passive coupler** redistributes the optical signal without optical-to-electrical conversion. **Active couplers** are electronic devices that split or combine the signal electrically and use fiber-optic detectors and sources for input and output.

Figure 6-12 shows the design of a basic fiber-optic coupler. A basic fiber-optic coupler has N input ports and M output ports. N and M ports typically range from 1 to 64. The number of input ports and output ports varies, depending on the intended application for the coupler. Types of fiber-optic couplers include optical splitters, optical combiners, X couplers, star couplers, and tree couplers.

## AREA LIGHTING SYSTEMS

This section covers streetlighting, floodlighting, and security lighting systems. When properly constructed and installed, these original basewide lighting systems will provide years of trouble-free operation with a minimum of minor maintenance and bulb changing required to keep the system fully operational.

Several factors can change the base requirements for area lighting. These factors include such changes as facility usage, updating of systems, changes in the base mission, or expanding existing systems.

With the cost of energy rising daily, any system that can provide a higher level of efficiency for the energy used must be considered. The use of the newer high-pressure discharge systems for lighting seems to offer savings both in the lifespan of the bulbs and in the lumens per watt of energy used These systems are replacing the older incandescent systems in an ever-increasing pace. The higher initial cost of these systems is being offset by the efficiency of the energy used and savings of energy dollars.

## TERMINOLOGY AND DEFINITIONS

You will need an understanding of lighting techniques and effects to understand the physical concepts and terminology involved in lighting systems. We will use both the American Standard (AS) and the metric system (SI) when discussing lighting concepts. The AS standards will be without brackets, whereas the SI terms will be noted in square brackets [ ].

The candlepower [candela], abbreviated cp [cd], is the unit of luminous intensity. It is comparable to the voltage in an electrical circuit and represents the force that generates the light you can see. An ordinary wax candle has a luminous intensity of approximately one

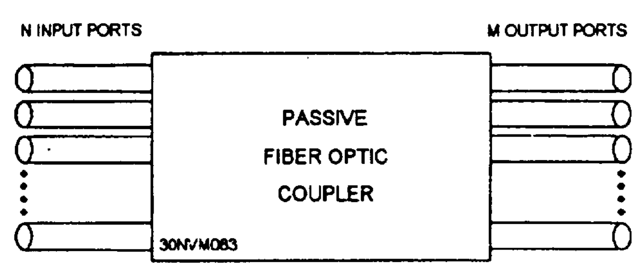


**Figure 6-12.—Basic passive fiber-optic coupler design.**

candlepower [candela], hence the name (fig. 6-13). A candle radiates light equally in all directions. If you imagine such a source surrounded by a transparent sphere of one foot [meter] radius (figure) than by definition, the amount of luminous energy (flux) emanating from one square foot [meter] of surface on the sphere is one lumen [lumen], abbreviated lm.

Since there are 40 square feet [meters] of surface area in such a sphere, it follows that a source of one candlepower [candela] intensity produces 40 or 12.57 lm (a lumen is a unit of light quantity), and in terms of power is equal to 0.0015 watt. It therefore also follows that 1-cp [cd] source produces 12.57 times 0.0015 watt; that is, 0.0189 watt or approximately 1/50 watt of luminous energy. The lumen, as luminous flux, or quantity of light, is comparable to the flow of current in an electrical circuit

One lumen of luminous energy occurrence on one square foot of area produces an illumination of one footcandle (fc). When the area is expressed in square meters, the illumination is expressed in lux (lx). If you were to consider a light bulb to be comparable to a sprinkler head, then the amount of water released would be the lumens and the amount of water per square foot (meter) of floor area would be the footcandles [lux]. The metric unit, lux, is smaller than the corresponding unit, footcandles, by a ratio of approximately 10 to 1. In order to change footcandle to lux, you would multiply by 10.764.

Restating what you have just learned mathematically, it would look like this:

$$footcandles = \frac{lumens}{square\ feet\ of\ area}$$

Or

$$lux = \frac{lumens}{square\ meter\ of\ area}$$

### High Intensity Discharge Lighting

Efforts to improve the power efficiency and reduce the maintenance costs led to the development of a new family of lighting that has been generally categorized as high--intensity-discharge lamps (HID). These lamps all have a negative-resistance characteristic. This means that the resistance decreases as the lamps heat up. As the resistance decreases, the current increases. In fact, the current will increase indefinitely unless a current--limiting device is provided. All gaseous conduction HID lamps, therefore, have current limiters, called **"ballasts."** Lamp life and more light per watt are two main advantages that HID lamps have over incandescent bulbs. The basic types of HID lamps used in area lighting consist of three groups of lamps:

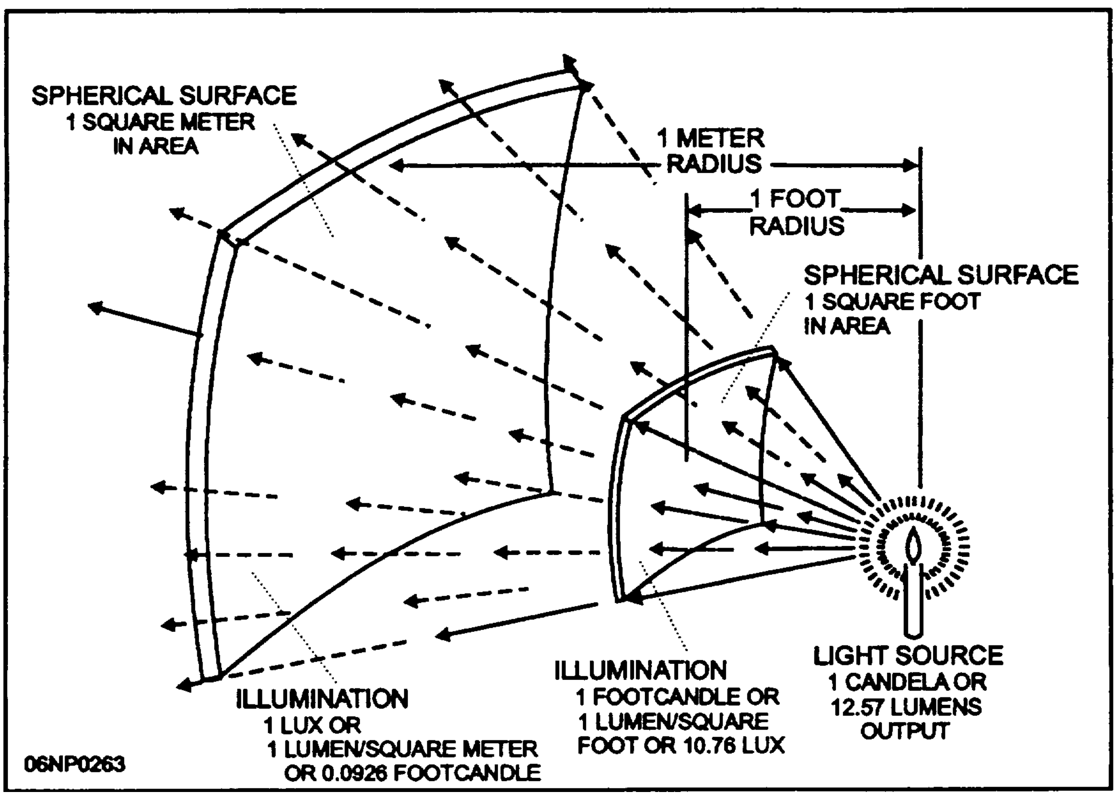


**Figure 6-13.—Relationship between a light source of one candlepower and the illumination produced.**

mercury lamps, metal halide lamps, and high-pressure sodium lamps. All high-intensity-discharge lamps produce light from an arc tube that is usually contained in an outer glass bulb.

Figure 6-14 shows the basic configuration of a HID lamp. In these lamps, a material, such as sodium, mercury, or metal halide, is added to the arc tube. In design, the lamp has three electrodes—one acting as a cathode and the other as an anode with the other electrode being used for starting. The arc tube contains small amounts of pure argon gas, halide salts, sodium, and vapor to aid in starting. Free electrons are accelerated by the starting voltage. In this state of acceleration, these electrons strike atoms and displace other electrons from their normal atomic positions. Once the discharge begins, the enclosed arc becomes the light source.

Commercial companies that produce these light bulbs claim a 100-percent increase in lamp life over tungsten filament bulbs that produce the same amount of light. The power in watts required to operate these lamps is less than one half of that required for filament lamps. The initial cost of the components for lights is substantially greater as these lights will require ballasts; however, this cost can be made up later by the savings of energy costs. The selection of lighting fixtures will depend on budgeted dollars for new installation projects versus maintenance dollars.

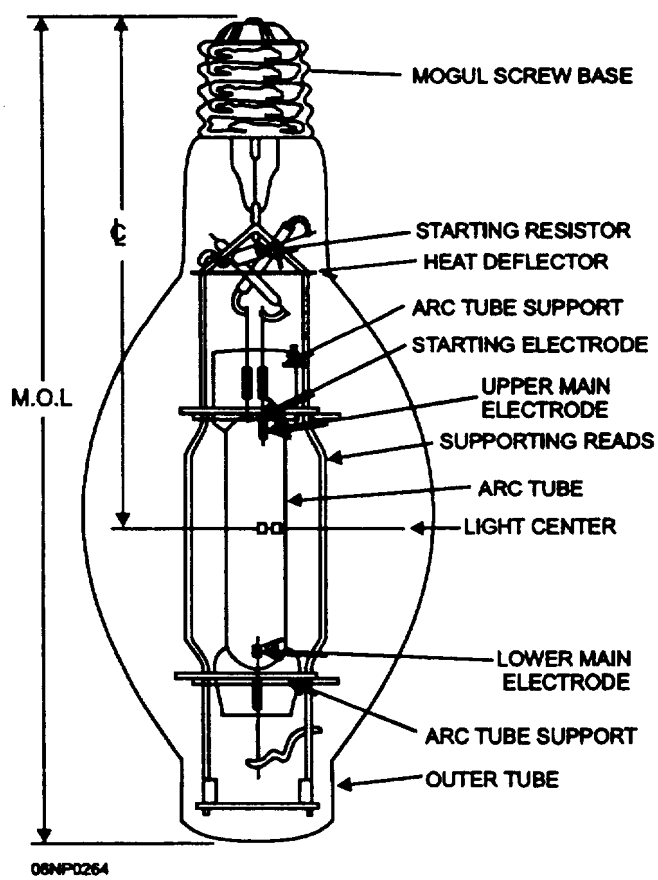


**Figure 6-14.—HID lamp configuration.**

Most discharge lighting fixtures are supplied with the required ballast installed in the fixture. In some cases ballasts, usually called transformers, are externally installed.

### High Pressure Mercury Lamps

This lamp consists of a quartz arc tube sealed within an outer glass jacket or bulb. The inner arc tube is made of quartz to withstand the high temperatures, resulting when the lamp builds up to normal wattage. Two main electronemissive electrodes are located at opposite ends of the tube; these are made of coiled tungsten wire. Near the upper main electrode is a third, or starting, electrode in series with a ballasting resistor and connected to the lower main-electrode lead wire.

The arc tube in the mercury lamp contains a small amount of pure argon gas that is vaporized. When voltage is applied, an electric field is set up between the starting electrode and the adjacent main electrode. This ionizing potential causes current to flow, and, as the main arc strikes, the heat generated gradually vaporizes the mercury. When the arc tube is filled with mercury vapor, it creates a low-resistance path for current to flow between the main electrodes. When this takes place, the starting electrode and its high-resistance path become automatically inactive.

Once the discharge begins, the enclosed arc becomes a light source with one electrode acting as a cathode and the other as an anode. The electrodes will exchange functions as the ac supply changes polarity.

The quantity of mercury in the arc tube is carefully measured to maintain quite an exact vapor pressure under design conditions of operation. This pressure differs with wattage sizes, depending on arc-tube dimensions, voltage-current relationships, and various other design factors.

Efficient operation requires the maintenance of a high temperature of the arc tube. For this reason, the arc tube is enclosed in an outer bulb made of heat-resistant glass that makes the arc tube less subject to surrounding temperature or cooling by air circulation. About half an atmosphere of nitrogen is introduced into the space between the arc tube and the outer bulb. The operating pressure for most mercury lamps is in the range of two to four times the atmospheric pressure. Lamps can operate in any position; however, light output is reduced when burned in positions other than vertical. Mercury lamps for lighting applications range in wattage from 40 to 1,000 watts. The 175- and 400-watt types are the most popular. Mercury lamps are used in streetlighting, security lighting, and outdoor area lighting. In new installations today, mercury lamps are being replaced with more efficient metal halide or high-pressure sodium systems.

### Metal Halide Lamps

The halide lamps are similar to mercury lamps in construction because the lamp consists of a quartz arc tube mounted within an outer glass bulb; however, in addition to mercury, the arc tubes contain halide salts, usually sodium and scandium iodide. During lamp operation, the heat from the arc discharge evaporates the iodide along with the mercury. The result is an increase in efficiency approximately 50 percent higher than that of a mercury lamp of the same wattage together with excellent color quality from the arc.

The amount of iodide vaporized determines lamp efficiency and color and is temperature-dependent. Metal halide arc tubes have carefully controlled seal shapes to maintain temperature consistency between lamps. In addition, one or both ends of the arc tube are coated to maintain the desired arc-tube temperature. There is some color variation between individual metal halide lamps owing to differences in the characteristics of each lamp.

Metal halide lamps use a starting electrode at one end of the arc tube that operates in the same manner as the starling electrode in a mercury lamp. A bimetal shorting switch is placed between the starting electrode and the adjacent main electrode. This switch closes during lamp operation and prevents a small voltage from developing between the two electrodes, that in the presence of the halides could cause arc-tube seal failure.

### High Pressure Sodium Lamps

The high-pressure sodium lamp, commonly referred to as HPS, has the highest light-producing efficiency of any commercial source of white light. Like most other high-intensity-discharge lamps, high-pressure sodium lamps consist of an arc tube enclosed within an outer glass bulb. The arc operates in a sodium vapor at a temperature and pressure that provide a warm color with light in all portions of the visible spectrum at a high efficiency. Owing to the chemical activity of hot sodium, quartz cannot be used as the arc-tube material; instead, high-pressure sodium arc tubes are made of an alumina ceramic (polycrystalline alumina oxide) that can withstand the corrosive effects of hot sodium vapor.

There are coated-tungsten electrodes sealed at each end of the arc tube. The sodium is placed in the arc tube in the form of a sodium-mercury amalgam that is chemically inactive. The arc tube is filled with xenon gas to aid in starting.

High-pressure sodium lamps are available in sizes from 35 to 1,000 watts. They can be operated in any burning position and have the best lumen-maintenance characteristic of the three types of HID lamps. Except for the 35-watt lamp, most high-pressure sodium lamps have rated lives of more than 24,000 hours. The 35-watt lamp has a rated life of 16,000 hours. The 50-, 70-, and 150-watt sizes are available in both a mogul-base and a medium-base design.

### Fluorescent Lighting

Fluorescent lamps of high-pressure, hard glass are used to some extent for floodlighting where a low-level, highly diffused light is desired. This would include club parking lots, outside shopping areas, parks, or grass areas. This bulb is much the same in operation as the mercury-vapor lamp with the exception that the fluorescent tube has an inside coating of material, called phosphor, that gives off light when bombarded by electrons. In this case, the visible light is a secondary effect of current flow through the lamp. Just like the HID lamps, the fluorescent lamp requires a ballast for operation. The color produced by the light depends on the type of phosphor material used.

### High-Intensity-Discharge Lamp Ballasts

All HID lamps have a negative-resistance characteristic. As a result, unless a current-limiting device is used, the lamp current will increase until the lamp is destroyed. Ballasts for HID lamps provide three basic functions: to control lamp current to the proper value, to provide sufficient voltage to start the lamp, and to match the lamp voltage to the line voltage. Ballasts are designed to provide proper electrical characteristics to the lamp over the range of primary voltage stated for each ballast design. Typical ballasts are shown in figure 6-15.

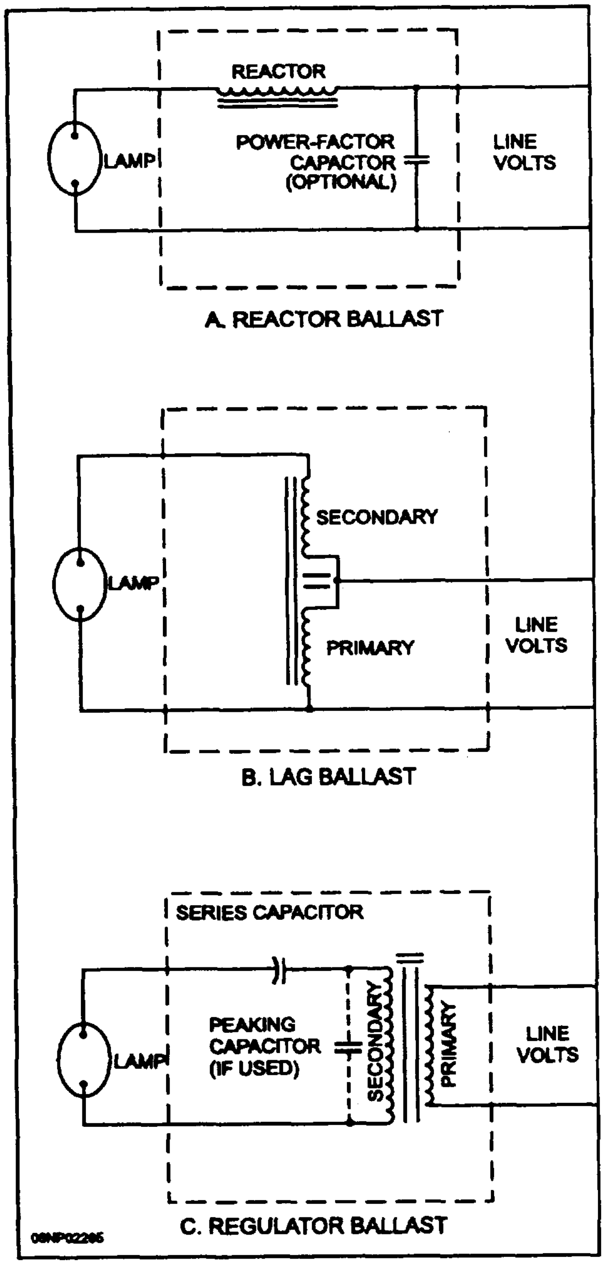


**Figure 6-15.—Mercury-lamp ballast circuits.**

Ballasts are classified into three major categories depending on the basic circuit involved: nonregulating, lead-type regulating, and lag-type regulating. Each type has different operating characteristics.

**High-Intensity-Discharge System Troubleshooting**

HID lighting systems include the power supply system (wiring, circuit breakers, and switches), lighting fixture (socket, reflector, refractor or lens, and housing), ballast, lamp, and frequently a photoelectric cell to turn on the fixture at dusk. When an HID system does not operate as expected, the source of the problem can be in any part of the total system.

It is important to understand normal lamp-failure characteristics to determine whether or not operation is abnormal. All HID lamps have expected lamp-failure patterns over life; these are published by lamp manufacturers. Rated life represents the expected failure point for one third to one half of the lamps, depending on the lamp type and the lamp manufacturer's rating.

The end-of-life characteristics vary for the different HID lamps of the following types:

1. *Mercury.* Normal end of life is a nonstart condition or low-light output, resulting from blackening of the arc tube that is due to electrode deterioration during the life of the lamp.

2. *Metal halide.* Normal end of life is a nonstart condition, resulting from a change in the electrical characteristic when the ballast can no longer sustain the lamp. Lamp color at the end of life will usually be warmer (pinker) than that of a new lamp due to arc-tube blackening because of changes in thermal balance within the tube. The lamp manufacturers' recommendations regarding metal-halide lamp enclosures should be reviewed.

3. *High-pressure sodium.* Normal end of life is on-off cycling. This results when an aging lamp requires more voltage to stabilize and operate than the ballast is able to provide. When the normally rising voltage of the lamp exceeds the ballast output voltage, the lamp is extinguished. Thea, after a cool-down period of about 1 minute, the arc will restrike and the cycle is repeated. This cycle starts slowly at first and then increases in frequency if the lamp is not replaced. Ultimately, the lamp fails because of overheating of the arc-tube seal.

There are four basic visual variations in the lamp of a HID lighting system that indicates when a problem may exist: (1) the lamp does not start, (2) the lamp cycle is on and off or is unstable, (3) the lamp is extra bright, or (4) the lamp is dim. The following table indicates the most likely possible causes for each of these system conditions.

| HID-system conditions | Other than lamp | Lamp |
|---|---|---|
| Lamp does not start. | Ballast failure<br>Incorrect or loose wiring<br>Low supply voltage<br>Low ambient temperature<br>Circuit breakers tripped<br>Inoperative photocell<br>Starting-aid failure (HPS) | Lamp loose in socket<br>Improper lamp wattage<br>Normal end of life<br>Lamp internal structure broken |
| Lamp cycle is on and off or is unstable. | Low supply voltage<br>Incorrect ballast<br>High supply voltage (HPS)<br>Ballast voltage low<br>System voltage dipping<br>Fixture concentrating energy on lamp (HPS) | Normal end of life (HPS)<br>Lamp operating voltage too high (HPS)<br>Lamp arc tube unstable |
| Lamp is extra bright. | Shorted or partially shortedballast or capacitor<br>Overwattage operation | Improper lamp wattage<br>High lamp voltage |
| Lamp is dim. | Low supply voltage<br>Incorrect ballast<br>Low ballast voltage to lamp<br>Dirt accumulation<br>Ballast capacitor shorted<br>Corroded connection in fixture | Improper lamp wattage<br>Low lamp voltage<br>Lamp difficult to start |

**FIXTURES**

There are fixture configurations to meet almost any lighting requirement or design. While the basic purpose of the fixture is to hold and prevent damage to the lamps and lamp sockets, the fixture also helps direct the light beams into the lighting patterns desired. The fixture, with its reflector and lens, determines the quality of the light being produced. Reflectors can either concentrate or diffuse light rays, and the lens can pass or refract light rays. Quite often, the lens may be used to do both from one light source; that is, part of the light rays are refracted to produce a soft, even spread of light in the outer part, while the light rays are concentrated in other areas of the lens to produce a bright, hard light at a specific area. Some streetlight fixtures are examples of this. The sides of the lenses produce a general diffused lighting to prevent blinding automobile operators and, at the same time, they produce a bright light pattern below the lamp along the curb.

Flood or security lighting fixtures may be either open or enclosed. The open fixtures provide higher maintained efficiency and more accurate beam control. The open fixture will, under some conditions, require a "hard glass" bulb to prevent bulb breakage.

Most fixtures will have provisions for mounting ballasts (transformers) within the fixture and will provide protection for the ballast. In some cases, particularly in light pole lighting, the ballasts may be mounted in the pole base and not mounted in the fixture. Several methods of fixture attachment are possible and should be considered when fixtures for a particular job are ordered The location and job determine whether the fixture is suspended, bracket-mounted, or arm-mounted. Most brackets can be attached either to wood or metal support structures. In either case, the fixture should be firmly attached to the structure so that precise aiming for light distribution can be made.

## LIGHT CIRCUITS

As we stated earlier, a number of light systems are in use today, such as streetlights, floodlights, and security lights. These systems are either series or multiple (parallel), depending on how they are used and the equipment available.

### SERIES AND MULTIPLE CIRCUITS

The series circuit is supplied by a regulating transformer that gives a constant current, usually of 6.6 amperes, to the lighting circuit. If a higher amperage is required, autotransformers are available for stepping up the current to 15 or 20 amperes. This higher amperage permits the use of more rugged lamp filaments that give longer life for lamps of equal candlepower and higher lamp efficiency.

The multiple (parallel) circuit consists of a number of streetlights supplied by a distribution transformer, delivering a constant low voltage to a circuit or secondary main that also supplies other loads; however, running secondary conductors any great distance to supply a parallel connected lamp or a group of lamps is impractical because of the excessive voltage drop.

The cost of the multiple luminaire is low compared to the series type because the low voltage allows for the elimination of other luminaire accessories. This saving is largely offset, however, by the increased requirement for control devices and the copper wire cost. Lamp life and efficiency are comparatively low, and the illumination is not as uniform as in a series circuit.

In choosing a system, here are a few suggestions that may aid in your selection.

- If the total wattage of the circuit exceeds 2 kilowatts or more than 15 lights, consider a series lighting system.

- When extending an existing system, use the existing circuit.

- If low-voltage capacity exists at the proposed location, use a multiple system, even though the load exceeds 2 kilowatts.

- When several small lights are to be spaced rather far apart and no low-voltage secondary exists along the route, use the series system regardless of the load size or the number of lights.

- When estimates show that one type of system will save money and time, use the more economical system.

#### Series Circuits

Let us consider a series streetlight system. The power for the circuit will be supplied from the base primary distribution lines, through fuse cutouts, to an oil switch, and from the oil switch to a constant-current regulator (fig. 6-16). The constant-current regulator will supply power to the series loops and, thus to the individual lamps. While the current (normally 6.6 amperes) remains constant, the voltage of the circuit is equal to the sum of the voltages of all the lamps plus the voltage drop in the wire. With enough lamps connected in series, the circuit can become a **high-voltage circuit.**

The series circuit is easily controlled, but any break, such as a burned-out filament in a lamp, interrupts the

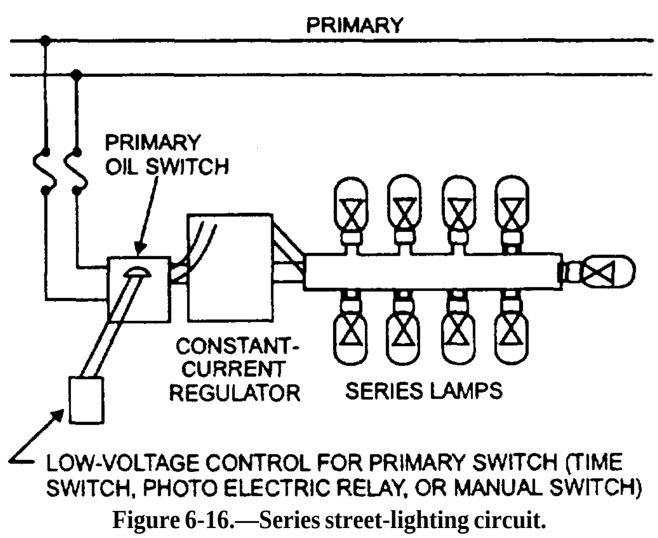


**Figure 6-16.—Series street-lighting circuit.**

entire circuit. The use of film-disk cutouts (fig. 6-17) in the lamp socket prevents lamp failure from interrupting the circuit. The cutouts consist of two metal disks separated by a thin film of insulating material. The insulating film is held in place by the spring pressure of the contact disks. When the filament of the lamp burns out, the entire circuit voltage appears across the film disk. This is more than sufficient to puncture the film and close the circuit between the two metallic disks, thereby bypassing the burned-out filament. In later series circuits, an isolation transformer is used to eliminate the need for the film disk fixture. The primary winding of the isolation transformer is connected in series with the power source and the secondary winding provides power to the light bulb. Since the primary winding is isolated from the secondary winding, a burned out bulb will not interrupt the continuity of the lighting circuit.

A series circuit is installed using only one wire, as shown in figure 6-18(a). Some of the lamps are connected in the outgoing wire, and the rest are connected in the return wire. This is called an "open-loop" series circuit. An open-loop circuit is less expensive initially, but troubleshooting is difficult, time consuming, and costly.

To make it possible to locate a fault like an open circuit or a ground, it is desirable to bring the outgoing and return conductors close together in numerous places so that the circuit can be easily short-circuited. Such a circuit is called a “closed-loop” circuit, as shown in figure 6-18(b). Sometimes the circuit is arranged to combine the open- and closed-circuit features, as shown

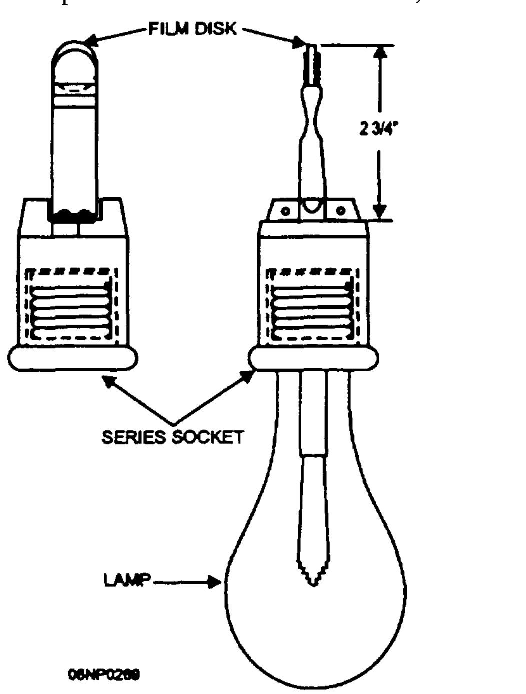

Figure 6-17.—Series lamp, socket, and film-disk cutout.

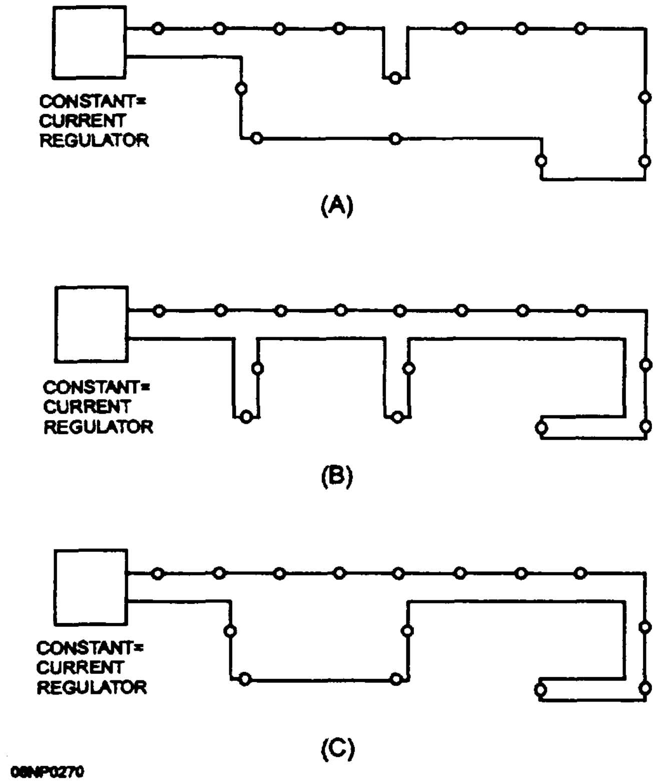

**Figure 6-18.—Diagrams of (a) open loop, (b) closed bop, and (c) combined open and closed loop series circuits.**

in figure 6-18(c). The use of the closed-loop or the combination circuit makes troubleshooting easier.

Installing the series circuit on the same crossarm as the primary-distribution conductor is usually the most economical. When two primary crossarms are used, the streetlight wires should be carried on the lower arm in the end-pin position. When two separate single-conductor street circuits are on the same crossarm, they should not be placed in adjacent pin positions because of confusion in troubleshooting.

Insulator sizes should be based on the open-circuit voltage of the largest regulator used and are usually the same size as those used for primary distribution. White insulators should be used on a series street circuit to distinguish them from the primary distribution insulators and to assist in identifying the circuits for operating and maintenance work. Small strain insulators should be used for cutting in individual lamps or loops of five lamps or fewer. Equivalent voltage insulators with automatic line splices may also be used. If the loop consists of more than five lamps, a primary disk insulator is used. The insulator is usually cut in after the conductors have been strung.

The conductor size should be No. 6 medium hard-drawn copper or its mechanical equivalent. Although No. 8 hard-drawn copper is usually too weak for longer spans, the use of copperweld or similar conductors of

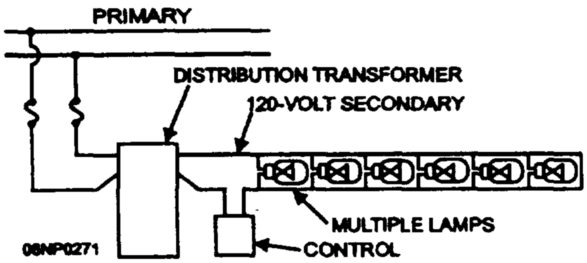


**Figure 6-19.—Multiple street-lighting circuit.**

high-mechanical strength overcomes the difficulty. Conductor sag should be the same as for primary distribution.

Constant-current regulators should be protected on overhead circuits by lightning arresters on both the primary and secondary sides.

### Multiple Circuits

The multiple streetlight system uses a distribution transformer of the proper size as service equipment. (See fig. 6-19.) Notice that the transformer is fed directly through fuse cutouts from the base primary distribution system. The control for the circuit is connected into one line of the secondary side. The selection of output voltage of the transformer depends on the voltage required for the individual lamps that are installed. Depending on the types of lamps selected, this voltage may be from 120 volts to 480 volts. You must know the type of lamp that will be used in the circuit before you can properly select the transformer to feed the streetlight system.

## COMPONENTS AND CONTROLS

There are many components required to construct an area lighting system. These include constant-current transformers, relays, controls, fixtures, wiring, and lamps. Controls can be manual, automatic, or a combination.

### Constant-Current Transformer

The constant-current transformer, usually called a regulator, has a movable secondary winding that automatically changes position to provide constant current for any load within its full-load rating. The balance point between coil weight and magnetic force may be adjusted to provide the desired output current.

A moving-coil regulator is recommended because of the close regulation required for streetlighting work. It consists of a fixed primary coil and a movable secondary coil on a laminated core. Voltage applied to the primary winding causes voltage to be induced in the secondary winding. When the secondary circuit is closed, the magnetic field in the secondary reacts with the primary-coil field to push the movable coil up. The balance point between coil weight and magnetic force is designed to provide the desired secondary current (usually 6.6 amperes).

On most existing installations, the constant-current regulator is of the outdoor type. Three main types of installation are used for these regulators: two-pole platform, timber or steel construction single-pole platform, and pole mounted. Any regulator larger than 20 kilovolt amperes should be mounted on a platform.

Constant-current regulators should be loaded as near 100 percent as possible since both efficiency and power factor are best at this load. Specifications of the American Institute of Electrical Engineers (AIEE) require constant-current transformers to deliver the rated secondary current at lo-percent overload. A larger size regulator should not be installed before this 10-percent overload is reached. When larger regulators must be installed and are not readily available, a booster transformer may be used with its secondaries connected into the series street circuit and its primaries connected to the primary feeder supplying the regulator (fig. 6-20).

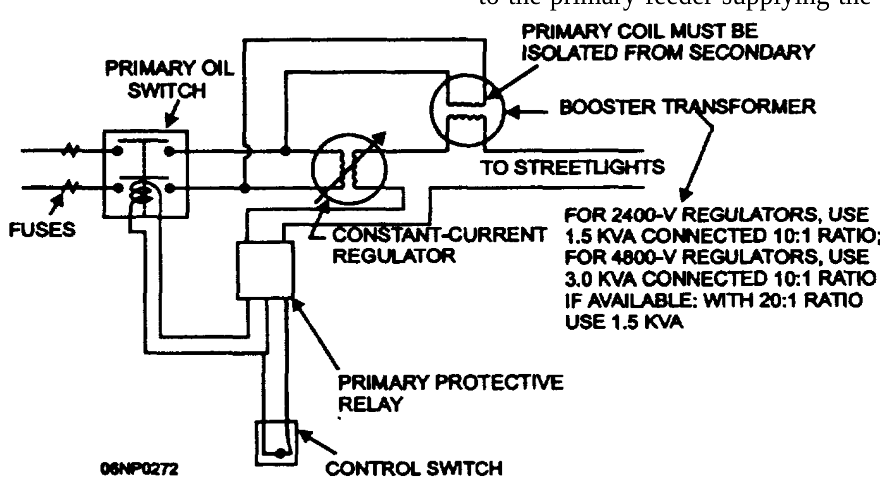


**Figure 6-20.—Method of relieving slightly overloaded regulators with a distribution or booster transformer.**

Since transformers used for this purpose should have secondary bushings insulated for the high voltage of the series street circuit, a special booster transformer is preferred to an ordinary distribution transformer for use with constant-current regulators of 10 kilowatts and larger. In using a booster transformer, the primary coil must be isolated from the secondary coil that necessitates removing any internal lead connecting the two coils. The additional load handled by this device equals the product of the street-circuit current and the secondary voltage of the transformer. Thus, if a 2,400/240-volt transformer is used, the additional load

STRAIGHT-SERIES LAMPS WITH FILM CUTOUT

| REGULATOR RATING (kW) | CIRCUIT RATING IN AMPERES | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6.6 | | | | | | 15 | 20 | | | | |
| | 600 LUMENS | 800 LUMENS | 1,000 LUMENS | 2,500 LUMENS | 4,000 LUMENS | 6,000 LUMENS | | 4,000 LUMENS | 6,000 LUMENS | 10,000 LUMENS | 15,000 LUMENS | 25,000 LUMENS |
| 1 | 21 | 17 | 14 | 6 | 4 | 2 | 4 | 3 | 3 | | | |
| 2 | 42 | 34 | 28 | 12 | 8 | 5 | 8 | 7 | 6 | 3 | 2 | 1 |
| 3 | 64 | 51 | 43 | 18 | 12 | 8 | 12 | 11 | 9 | 5 | 3 | 2 |
| 5 | 107 | 86 | 72 | 30 | 18 | 13 | 20 | 19 | 13 | 9 | 6 | 3 |
| 7.5 | 161 | 129 | 108 | 45 | 30 | 20 | 30 | 29 | 21 | 12 | 9 | 5 |
| 10 | 214 | 172 | 144 | 60 | 40 | 26 | 40 | 39 | 28 | 16 | 11 | 7 |
| 15 | 321 | 258 | 216 | 90 | 60 | 40 | 60 | 58 | 47 | 25 | 16 | 10 |
| 20 | 428 | 344 | 288 | 120 | 80 | 55 | 80 | 78 | 56 | 34 | 22 | 13 |
| 25 | 535 | 430 | 360 | 150 | 100 | 66 | 100 | 97 | 70 | 42 | 28 | 17 |
| 30 | 642 | 516 | 432 | 180 | 120 | 80 | 121 | 117 | 85 | 50 | 34 | 21 |
| UNIT kW* | .047 | .058 | .069 | .167 | .250 | .375 | .249 | .256 | .354 | .600 | .880 | 1.43 |

LAMPS WITH AUTO TRANSFORMERS AND LAMPS WITH ISOLATION TRANSFORMERS

| REGULATOR RATING (kW) | CIRCUIT RATING IN AMPERES | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 15 | 20 | | | | 6.6 | | 15 | 20 | | | |
| | 4,000 LUMENS | 6,000 LUMENS | 10,000 LUMENS | 15,000 LUMENS | 25,000 LUMENS | 1,000 LUMENS | 25,000 LUMENS | 4,000 LUMENS | 6,000 LUMENS | 10,000 LUMENS | 15,000 LUMENS | 25,000 LUMENS |
| 1 | 3 | 2 | 1 | 1 | 0 | 12 | 5 | 3 | 2 | 1 | 1 | 0 |
| 2 | 7 | 5 | 3 | 2 | 1 | 24 | 10 | 7 | 5 | 3 | 2 | 1 |
| 3 | 11 | 7 | 4 | 3 | 2 | 32 | 15 | 10 | 7 | 4 | 3 | 2 |
| 5 | 18 | 13 | 8 | 5 | 3 | 53 | 25 | 17 | 12 | 7 | 5 | 3 |
| 7.5 | 27 | 19 | 12 | 8 | 5 | 80 | 38 | 26 | 18 | 11 | 7 | 5 |
| 10 | 37 | 26 | 16 | 11 | 6 | 107 | 51 | 35 | 25 | 15 | 10 | 6 |
| 15 | 55 | 39 | 24 | 16 | 10 | 160 | 76 | 52 | 37 | 23 | 15 | 10 |
| 20 | 74 | 52 | 32 | 22 | 12 | 215 | 102 | 70 | 50 | 30 | 20 | 12 |
| 25 | 92 | 65 | 40 | 27 | 16 | 268 | 127 | 87 | 62 | 38 | 25 | 16 |
| 30 | 110 | 78 | 48 | 32 | 20 | 322 | 152 | 104 | 74 | 46 | 30 | 20 |
| UNIT kW* | .273 | .384 | .625 | .935 | 1,500 | .093 | .197 | .288 | .405 | .650 | 1.000 | 1.500 |

HIGH-INTENSITY DISCHARGE LAMPS

LAMP CAPAFITY OF REGULATORS IS LIMITED BY STARTING CURRENT. DETERMINE UNIT kW BY MULTIPLYING LAMP WATTAGE BY THE FOLLOWING FACTORS: 2.1 FOR AMBIENT TEMPERATURES NOT BELOW +35°F (+2°C)
2.5 FOR AMBIENT TEMPERATURES TO -30°F (-34°C)

THE PROPER SIZE REGULATOR TO SELECT IS THE SMALLEST RATING WHICH EXCEEDS THE SUM OF THE UNIT kW FOR ALL LAMPS ON THE CIRCUIT, REGARDLESS OF TYPE.

*UNIT kW IS THE APPROXIMATE kW CAPACITY REQUIRED FOR A SPECIFIC LAMP AND ITS ASSOCIATED TRANSFORMER OR BALLAST AS APPLICABLE.

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**Figure 6-21.—Approximate lamp capacity for street-lighting regulators.**

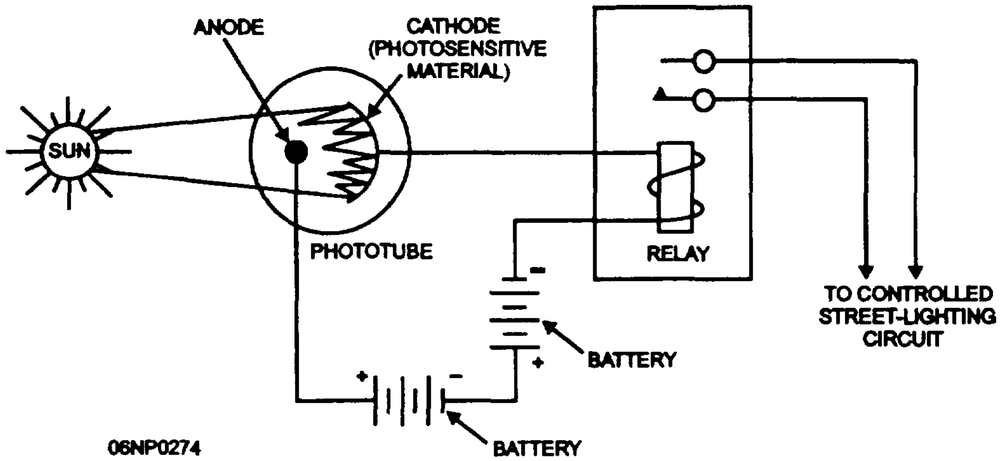


**Figure 6-22.—Photoelectric cell control circuit.**

that the street circuit can carry is 240 volts times 6.6 amperes or 1.584 kilowatts.

Figure 6-21 shows the maximum number of series lamps in the various sizes that may be used for full-load rating on a regulator. The average number of watts of energy consumption for each size lamp may be computed since the regulator ratings are based on their output. In this manner, the load of a circuit consisting of different size lamps may be computed.

Example: What size regulator would be required to supply the following lamps?

25—1,000-lumen, 6.6-ampere, straight-series lamps

50—2,500-lumen, 6.6-ampere, straight-series lamps

10—6,000-lumen, 20-ampere lamps with isolating transformer

Solution: Figure 6-21 shows that the average energy consumption of a 1,000-lumen, 6.6-ampere, straight-series lamp with film cutout is 69 watts per lamp. In a similar manner, the average energy consumption of a 2,500-lumen lamp is 167 watts, and a 6,000-lumen, 20-ampere lamp with isolating transformer is 405 watts. Totaling the combined load shows the following:

25 x 69 = 1,725 watts

50 x 167 = 8,350 watts

10 x 405 = 4,050 watts

14,125 watts or 14.1 kilowatts

Therefore, a 15-kilowatt regulator would be required.

**NOTE:** The table makes allowances for line losses in the average series street circuits.

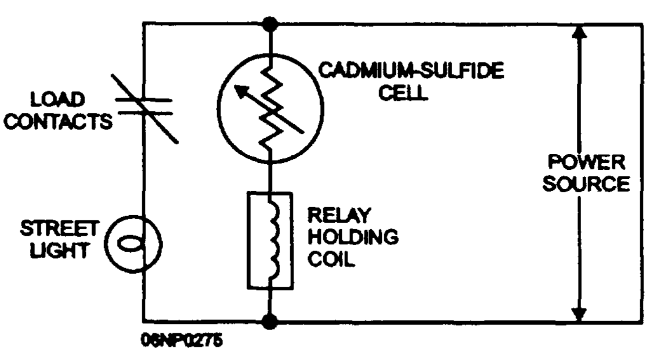


**Figure 6-23.—Cadmium-sulfide cell control circuit,**

## Control Circuits

Several methods are used to control the operation of area lighting systems. For recreational lighting, only a manual switch is required. On the other hand, streetlights and security lights have more sophisticated *controls.*

Lights normally are on during the hours of darkness or when unusual weather conditions indicate the need for artificial light. Although lights could be activated by assigning an individual to operate the controls manually, they are usually turned on and off by a combination of controls.

Most control circuits that you will encounter in the field use one of the following devices to control the lighting system: photoelectric cell (fig. 6-22), cadmium-sulfide cell (fig. 6-23), time clock, pilot wire relay (fig. 6-24), or cascading relays (fig. 6-25).

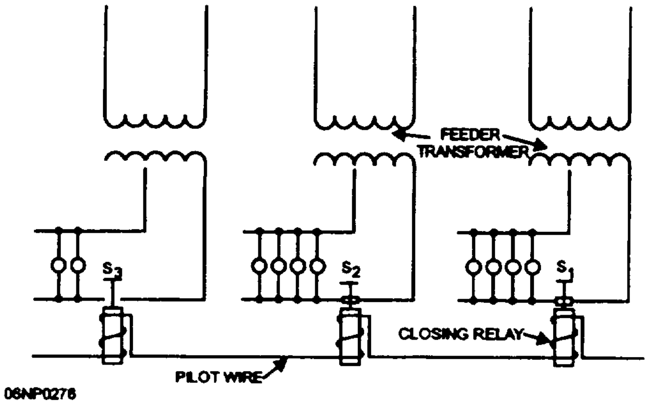


**Figure 6-24.—Pilot wire control of multiple-lighting circuits supplied from several feeder transformers.**

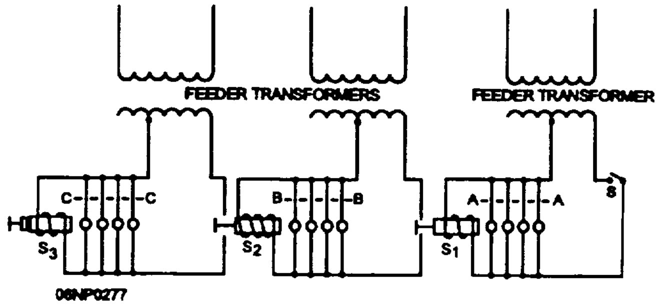


**Figure 6-25.—Cascade control of multiple-lighting circuits supplied from several feeder transformers.**